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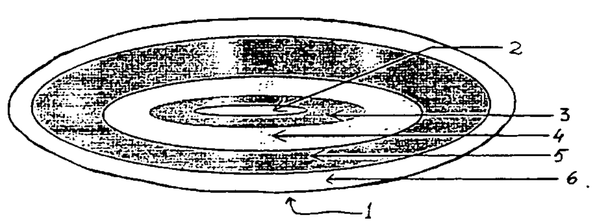
# (54) Title: DISPERSION OPTIMIZED FIBER WITH LOW DISPERSION AND OPTICAL LOSS

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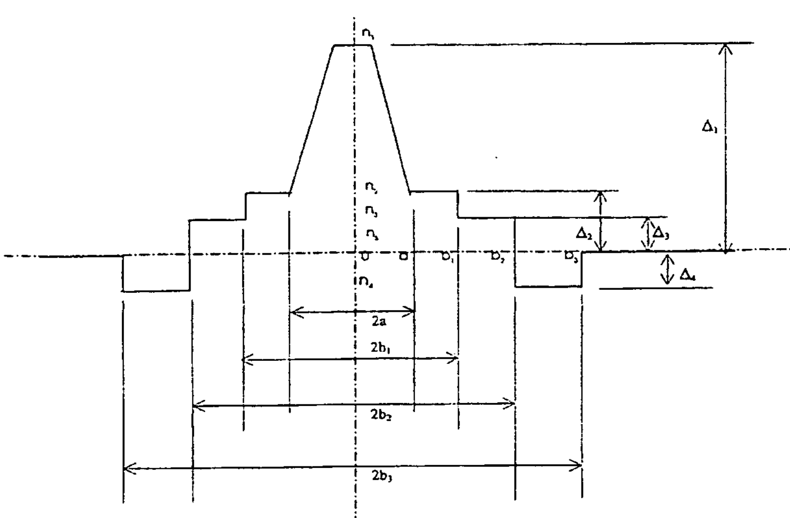


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**(57) Abstract:** A dispersion optimized fiber comprising a centre core, two side cores, a cladding and a outer glass, wherein first side core is provided onto outer periphery of center core, second side core is provided onto outer periphery of first side core and cladding region is provided onto outer periphery of second side core is disclosed, wherein centre core, first side core, second side core and cladding region have $n_1$, $n_2$, $n_3$ and $n_4$ refractive index respectively and $2a$, $2b_1$, $2b_2$ and $2b_3$ outer diameter respectively.. The refractive index of outer glass is $n_5$ and its diameter is selected to suit the requirement of desired fiber. The refractive indexes of said members are characterized by relationship $n_4<n_5<n_3<n_2<n_1$, and outer diameters of each member are characterized by $5.1\geq 2a\geq 6.2$ µm, $7\geq 2b_1\geq 9$ µm, $13\geq 2b_2\geq 15$ µm, $19\geq 2b_3\geq 22$ µm relationships.

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# TITLE OF INVENTION

Dispersion Optimized Fiber with Low Dispersion and Optical Loss

## Technical Field

The present invention relates to dispersion optimized fiber with low dispersion and optical loss, particularly it relates to a dispersion optimized fiber to provide low dispersion and optical loss between 1530 to 1565 nm (C-band) transmissions, more particularly it relates to single mode dispersion optimized fiber, which is suitable for transmission of higher bandwidth over long distances and yet has optimized effective area, cut-off wavelength and mode field diameter to achieve a high level of bend resistance for high bandwidth transmission.

## Background Art

Over the last decade, the optical fibers have been developed and installed as the backbone of interoffice networks for voice, video and data transmission. These are becoming important with growing and expanding telecommunication infrastructure. Their importance is further increasing because of their high bandwidth applicability. The higher bandwidth demand is further increasing exponentially with time because of rapid growth of information technology.

Conventionally, the multi-mode fiber at wavelength of 850 nm were used, which were replaced by single mode fibers with zero dispersion wavelength near 1310 nm. The single mode or monomode optical fibers have greater bandwidth than that of the multimode fibers. Therefore, the research has been directed towards the development of the single mode fibers, as these fibers were observed to have lower attenuation between the wavelength range from 1300 nm to 1550 nm. The transmission loss of single mode fibers is observed to be as low as 0.5 dB/km at 1300 nm wavelength and 0.2 dB/km at 1550 nm wavelength.

However, when single wavelength moved through 1550 nm window for lower attenuation, the single mode fibers were observed to have very high dispersion.

The major disadvantage of the single mode fibers with high dispersion at 1550 nm was that, it obstructed higher bit rate transmission. This disadvantage of single mode fibers has been overcome by the improved single mode fibers, known as dispersion shifted fibers, which have zero dispersion even when the wavelength shifted to 1550 nm.

In the prior art the optical fibers with minimum attenuation of light transmission and the dispersion shifted fibers with zero dispersion in the wavelength region of 1500 nm to 1600 nm band are being used. The fibers with simple step like refractive index profile have poor practical advantages. The dispersion shifted fibers with convex refractive index profile have better practical advantages and less flexural loss.

The known dispersion shifted fibers have higher refractive index in the center core and lower refractive index in the outer region. The relative difference in the refractive index is achieved by using different dopants. The commonly used dopants are germanium and fluorine, however, their flow rate and the temperature of doping are different in different known methods. The specific refractive index profile having selected refractive indexes and outer diameters of core and cladding region of the optical fiber is decided by the selection of dopants, their flow rates and temperatures of doping of the core and/or cladding regions, demarcation of core region into one or more core regions with one or more set of refractive indexes, the demarcation of cladding region into one or more cladding regions with one or more set of refractive indexes, the shape of core and cladding regions etc. These parameters decide the characteristic properties of thus obtained fiber and the applications of thus obtained fiber.

Therefore, the fibers known in the art are distinguished by way of their characteristic properties, which in-turn are decided by various parameters as

stated herein above. The fibers as known in the prior art either have low non-linearity but high bend loss or have low bend loss but less effective area or may have higher non-linearity and higher bend loss.

Therefore, the attempt had been to develop the fiber, which will have optimum characteristic properties, that is which will not sacrifice one of the characteristic property to achieve another characteristic property.

## Objects of the Invention

The main object of the present invention is to make a complete disclosure of a dispersion optimized fiber, which has low dispersion and optical loss, particularly between 1530 to 1565 nm wavelength band.

The another object of the present invention is to make a complete disclosure of a dispersion optimized fiber, which is suitable for long haul transmission.

Still another object of the present invention is to make a disclosure of a dispersion optimized fiber which not only has low dispersion and optical loss in 1530 to 1565 nm wavelength band but also has optimized effective area, cut-off wavelength and mode field diameter.

This is further an object of the present invention to make a disclosure of a dispersion optimized fiber which not only has high level of bend resistance for high bandwidth transmission but also has minimized non-linearities and low chromatic dispersion.

The other objects and preferred embodiments and advantages of the present invention will be more apparent from the following description when it is read in conjunction with the accompanying figures which are not intended to limit the scope of the present invention.

## Brief Disclosure of the Invention

In accordance to the present invention dispersion optimized fiber with low dispersion and optical loss between 1530 to 1565 nm (C-band) transmissions, particularly a dispersion optimized fiber, which is suitable for transmission of higher bandwidth over long distances and yet has optimized effective area, cut-off wavelength and mode field diameter, herein after referred to as MFD, to achieve a high level of bend resistance for high bandwidth transmission, minimized non-linearities and low chromatic dispersion with a low optical loss in the C-Band region is disclosed comprising a centre core, two side cores, a cladding region and a outer glass, wherein the first side core is provided onto the outer periphery of the center core, second side core is provided onto the outer periphery of the first side core and cladding region is provided onto the outer periphery of the second side core. According to the present invention the centre core, first side core, second side core and cladding region have $n_1$, $n_2$, $n_3$ and $n_4$ refractive index respectively and 2a, $2b_1$, $2b_2$ and $2b_3$ outer diameter respectively. The refractive index of outer glass is $n_5$ and its diameter is selected to suit the requirement of desired fiber. The refractive indexes of said members are characterized by relationship $n_4<n_5<n_3<n_2<n_1$, and outer diameters of each member are characterized by $5.1\geq 2a\geq 6.2$ μm, $7\geq 2b_1\geq 9$ μm, $13\geq 2b_2\geq 15$ μm, $19\geq 2b_3\geq 22$ μm relationships.

In accordance to the preferred embodiment of the present invention the cladding region is depressed cladding region and the side cores have lower refractive index than the center core. The refractive index of centre core, two side cores are positive and refractive index of cladding region is negative with respect to the refractive index of outer glass.

The other preferred embodiments and the advantages of the present invention will be more apparent from the following description when it is read in

conjunction with the accompanying figures which are not intended to limit the scope of the present invention.

## Brief Description of the Figures

Figure 1a of figure 1 shows a cut-section of dispersion optimized fiber in accordance to the preferred embodiments of the present invention.

Figure 1b of figure 1 shows the refractive index profile of dispersion optimized fiber in accordance to the preferred embodiments of the present invention.

Figure 2 shows the chromatic dispersion in the C-band region of dispersion optimized fiber in accordance to the preferred embodiments of the present invention.

Figure 3 shows the cut-off wavelength, using 2m-fiber as a reference length and measured on spectral analyzer, of the dispersion optimized fiber in accordance to the preferred embodiments of the present invention.

Figure 4 shows the intensity distribution along the diameter of the presently disclosed fiber for measuring the MFD of dispersion optimized fiber in accordance to the preferred embodiments of the present invention.

Figure 5 shows the attenuation spectra of dispersion optimized fiber in accordance to the preferred embodiments of the present invention.

## Detailed Description and Preferred Embodiments of Invention

Now referring to figure 1a showing a cut-section of dispersion optimized fiber in accordance to the preferred embodiments of the present invention, the dispersion optimized fiber 1 comprises of a centre core 2, two side cores 3 and 4,

which are referred to as first side core 3 and second side core 4, a cladding region 5 and a outer glass 6, and in accordance to the present invention the first side core 3 is provided onto the outer periphery of the center core 2, second side core 4 is provided onto the outer periphery of the first side core 3, cladding region 5 is provided onto the outer periphery of the second side core 4 and outer glass 6 is provided onto the outer periphery of the cladding region 5.

Now referring to figure 1b, which shows the refractive index profile of dispersion optimized fiber in accordance to the preferred embodiments of the present invention, centre core 2 has refractive index $n_1$, the first side core 3 has refractive index $n_2$, the second side core 4 has refractive index $n_3$, the cladding region 5 has refractive index $n_4$ and the outer glass 6 has refractive index $n_5$, and the centre core 2 has outer diameter 2a, the first side core 3 has outer diameter $2b_1$, the second side core 4 has outer diameter $2b_2$, the cladding region 5 has outer diameter $2b_3$. The diameter of the outer glass 6 can be selected to suit the requirement of desired dispersion optimized fiber.

In accordance to the present invention the relative refractive index difference between center core 2 and outer glass 6 is $\Delta_1$, the relative refractive index difference between first side core 3 and outer glass 6 is $\Delta_2$, the relative refractive index difference between second side core 4 and outer glass 6 is $\Delta_3$ and the relative refractive index difference between cladding region 5 and outer glass 6 is $\Delta_4$, that is $\Delta_1 = n_1 - n_5$, $\Delta_2 = n_2 - n_5$, $\Delta_3 = n_3 - n_5$, $\Delta_4 = n_4 - n_5$.

In accordance to one of the preferred embodiments of the present invention the refractive index of center core 2, side cores 3 and 4, cladding region 5 and outer glass are characterized by the following relationship –

$$n_4 < n_5 < n_3 < n_2 < n_1,$$

which indicates that the refractive indexes $n_2$, $n_3$, and $n_4$ of first side core 3, second side core 4 and cladding region 5 respectively are lower than the refractive index $n_1$ of the center core 2, and the refractive index $n_4$ of cladding region 5 is also lower than the refractive index $n_5$ of the outer glass 6. The refractive indexes $n_1$,

$n_2$ and $n_3$ of center core 2, first side core 3 and second side core 4 respectively are positive, and refractive index $n_4$ of cladding region 5 is negative with respect to the refractive index $n_5$ of outer glass 6, which is assigned zero value as reference.

In accordance to still another preferred embodiment of the present invention the cladding region 5 is depressed cladding region.

In accordance to another preferred embodiment of the present invention the relative refractive index differences $\Delta_1$, $\Delta_2$, $\Delta_3$ and $\Delta_4$ between center core 2 and outer glass 6, between first side core 3 and outer glass 6, between second side core 4 and outer glass 6 and between cladding region 5 and outer glass 6 respectively are characterised by the following relationships :

$$0.009 \geq \Delta_1 \geq 0.0135$$
$$0.0009 \geq \Delta_2 \geq 0.0019$$
$$0.0005 \geq \Delta_3 \geq 0.0009$$
$$-0.0001 \geq \Delta_4 \geq -0.0006$$

and $\Delta_1$, $\Delta_2$ and $\Delta_3$ are positive, and $\Delta_{-4}$ is negative with reference to outer glass 6.

In accordance to the preferred embodiment of the present invention the outer diameters of the centre core 2, first side core 3, second side core 4 and cladding region 5 are characterised by following relationships :

$$5.1 \geq 2a \geq 6.2\ \mu m$$
$$7 \geq 2b_1 \geq 9\ \mu m$$
$$13 \geq 2b_2 \geq 15\ \mu m$$
$$19 \geq 2b_3 \geq 22\ \mu m$$

The ratio of radius '$b_1$'of first side core 3 and of radius 'a' of centre core 2 [$b_1$/a] is about 1.5 ± 0.2, the ratio of radius '$b_2$' of second side core 4 and of radius 'a' of centre core 2 [$b_2$/a] is about 2.5 ± 0.2, the ratio of radius '$b_3$' of cladding region 5 and of radius 'a' of centre core 2 [$b_3$/a] is about 3.7 ± 0.2.

The presently disclosed dispersion optimized fiber having the profile as described and disclosed herein above has attenuation less than or equal to about 0.22 dB/km at 1550 nm, mode field diameter about 8.4 to 9.4 micrometer at 1550 nm, the effective area between about 55 to 65 micron$^2$ at 1550 nm, the cut-off wavelength less than about 1250 nm, the chromatic dispersion between about 2 to 8 ps/nm-km in 1530 – 1565 nm range, the polarized mode dispersion less than about 0.25 ps/km $^{0.5}$ and the microbending loss less than about 0.04 dB at 1550 nm. Further, the dispersion slope of the presently disclosed dispersion optimized fiber is about 0.060 ± 0.015 ps/nm$^2$km over the predefined wavelength region and the zero chromatic dispersion lies in between about 1470 – 1510 nm wavelength region.

It is observed from the foregoing description that the dispersion optimized fiber as disclosed in the present invention has low dispersion and optical loss between 1530 to 1565 nm (C-band) transmissions and is suitable for transmission of higher bandwidth over long distances.

The presently disclosed dispersion optimized fiber not only has optimized effective area, cut-off wave length and mode filed diameter but also has achieved a high level of bend resistance for high bandwidth transmission, minimized non-linearities and low chromatic dispersion with a low optical loss in the C-Band region.

In accordance to the preferred embodiment of the present invention the center core 2 of the presently disclosed dispersion optimized fiber 1 is doped with germanium doped in $SiO_2$, the first side core 3 is doped with germanium and fluorine doped in $SiO_2$, the second side core 4 is doped with germanium and

fluorine doped in $SiO_2$ and the depressed cladding region 5 is doped with germanium and fluorine doped in $SiO_2$. The doped dispersion optimized fiber of the present invention can be manufactured in accordance to any known process.

However, in accordance to one of the preferred embodiments of the present invention the center core 2 of the presently disclosed dispersion optimized fiber 1 is doped with germanium doped in $SiO_2$ preferably at 55 to 166 SCCm (standard cubic centimeter) flow rate and preferably at 1920 to 1960$^0$C temperature, the first side core 3 is doped with germanium and fluorine doped in $SiO_2$ preferably at 116 to 130 SCCm flow rate of germanium and preferably at 0.19 to 0.44 SCCm flow rate of fluorine and preferably at 1900 to 1916$^0$C temperature, the second side core 4 is doped with germanium and fluorine doped in $SiO_2$ preferably at 105 to 115 SCCm flow rate of germanium and preferably at 0.19 to 0.78 SCCm flow rate of fluorine and preferably at 1860 to 1892$^0$C temperature and the depressed cladding region 5 is doped with germanium and fluorine doped in $SiO_2$ preferably at 90.4 to 100.4 SCCm flow rate of germanium and preferably at 0.75 to 1.1 SCCm flow rate of fluorine and preferably at 1800 to 1844$^0$C temperature.

The germanium dioxide ($GeO_2$) is doped to quartz glass of the center core 2, first side core 3, and second side core 4 to increase the refractive index $n_1$, $n_2$, $n_3$. However, when, the refractive index $n_1$, $n_2$ and $n_3$ of the center core 2, first side core 3, and second side core 4 respectively is increased only by the doping of $GeO_2$, Rayleigh scattering in the glass increases which in turn increases the attenuation of light transmission of the optical fiber. The solution of this problem has been achieved by fluorine doping in the outer cladding region 5. The doping of fluorine decreases the viscosity mismatch between center core 1, first side core 3 and second side core 4 and at the same time increases the total refractive index difference between the core, comprising of center core 2, first side core 3, and second side core 4, and clad 5, that is, it reduces the attenuation by reducing the amount of $GeO_2$ incorporation in the core.

The dispersion optimized fiber design, as disclosed herein above has a unique profile which results in significantly less microbending sensitivity. Further, it has minimized non-linear effects, such as Four-Wave Mixing (FWM), Self Phase Modulation (SPM), Cross Phase Modulation (XPM) etc. and hence does not cause degradation of signal during high power transmission.

The problems of the non-linearities at higher bandwidth transmission are overcome by the presently disclosed dispersion optimized fiber having above stated characteristics.

Figures 2 to 5 illustrate various characteristics of the presently disclosed dispersion optimized fiber. Figure 2 discloses the chromatic dispersion characteristics of dispersion optimized fiber in accordance with the present invention, particularly, it discloses low dispersion and low slope that have been achieved from the preferred combination of refractive indices $n_1$, $n_2$, $n_3$, $n_4$ and $n_5$ and diameters 2a, $2b_1$, $2b_2$, $2b_3$ of the said members, as defined and described herein above, of the refractive index profile of the presently disclosed dispersion optimized fiber.

Figure 3 and figure 4 disclose the details regarding cut-off wavelength, for 2-meter reference length and mode field diameter characteristics of the presently disclosed dispersion optimized fiber in accordance with the present invention.

Figure 5 discloses spectral attenuation characteristics of the presently disclosed dispersion optimized fiber in accordance with the present invention, particularly it discloses a combination of low loss in the previously defined C-band and low OH peak, which has been created from the selection of flow rate of the dopants in accordance to the present invention.

The dispersion optimized fiber 1 according to the present invention is an optical fiber having a step index profile in case of first side core 3 and second side core 4 and trapezoidal profile in case of the center core 2.

The profile volume of the presently disclosed dispersion optimized fiber can be defined as follows :

$$\int_{0}^{a}\Delta n(r)rdr + \int_{a}^{b_1}\Delta n(r)rdr + \int_{b_1}^{b_2}\Delta n(r)rdr + \int_{b_2}^{b_3}\Delta n(r)rdr$$

where a, $b_1$, $b_2$, $b_3$ are as defined herein above and are characterised by the relationships as described herein above. The calculated profile volume of the presently disclosed dispersion optimized fiber 1 is in the range of 8 $\%\mu m^2$ to 23 $\%\mu m^2$.

The refractive index profile of the presently disclosed dispersion optimized fiber 1, as disclosed in figure 1 comprises of a germanium doped silica core, germanium and fluorine doped first and second side cores, germanium, fluorine doped depressed cladding and silica outer cladding, which is not intended to limit the scope of the present invention.

## Claims

1. Dispersion optimized fiber 1 with low dispersion and optical loss comprising a centre core 2, two side cores 3 and 4, a cladding region 5 and a outer glass 6, wherein said centre core 2 has refractive index $n_1$, the first side core 3 has refractive index $n_2$, the second side core 4 has refractive index $n_3$, said cladding region 5 has refractive index $n_4$ and said outer glass 6 has refractive index $n_5$ and said centre core 2 has outer diameter 2a, said first side core 3 has outer diameter $2b_1$, said second side core 4 has outer diameter $2b_2$, said cladding region 5 has outer diameter $2b_3$ and the relative refractive index difference between said center core 2 and said outer glass 6 is $\Delta_1$, the relative refractive index difference between said first side core 3 and said outer glass 6 is $\Delta_2$, the relative refractive index difference between said second side core 4 and said outer glass 6 is $\Delta_3$ and the relative refractive index difference between said cladding region 5 and said outer glass 6 is $\Delta_4$,
wherein the refractive indexes $n_1$, $n_2$, $n_3$, $n_4$ and $n_5$ of said members 2, 3, 4, 5 and 6 respectively are characterized by the following relationship :–

$$n_4 < n_5 < n_3 < n_2 < n_1,\ \text{and}$$

the relative refractive index differences $\Delta_1$, $\Delta_2$, $\Delta_3$ and $\Delta_4$ between said members 2, 3, 4, 5 and 6 are characterized by the following relationships :

$$0.009 \geq \Delta_1 \geq 0.0135$$

$$0.0009 \geq \Delta_2 \geq 0.0019$$

$$0.0005 \geq \Delta_3 \geq 0.0009$$

$$-0.0001 \geq \Delta_4 \geq -0.0006$$

and the relationship between said relative refractive index differences $\Delta_1$, $\Delta_2$, $\Delta_3$ and $\Delta_4$ between said members 2, 3, 4, 5 and 6, and said refractive indexes $n_1$, $n_2$, $n_3$, $n_4$ and $n_5$ of said members 2, 3, 4, 5 and 6 respectively are characterized by the following relationships :

$$\Delta_1 = n_1 - n_5$$

$$\Delta_2 = n_2 - n_5$$

$\Delta_3 = n_3 - n_5$ and

$\Delta_4 = n_4 - n_5$

and the outer diameters 2a, $2b_1$, $2b_2$ and $2b_3$ of said members 2, 3, 4 and 5 respectively are characterized by the following relationships :

$5.1 \geq 2a \geq 6.2$ µm

$7 \geq 2b_1 \geq 9$ µm

$13 \geq 2b_2 \geq 15$ µm

$19 \geq 2b_3 \geq 22$ µm

2. Dispersion optimized fiber according to claim 1, wherein said first side core 3 is provided onto the outer periphery of said center core 2, and said second side core 4 is provided onto the outer periphery of said first side core 3, and said cladding region 5 is provided onto the outer periphery of said second side core 4.

3. Dispersion optimized fiber according to claims 1 and 2, wherein said cladding region 5 is depressed cladding region.

4. Dispersion optimized fiber according to claims 1 to 3, wherein the ratio of radius '$b_1$' of said first side core 3 and of radius 'a' of said centre core 2 [$b_1/a$] is about 1.5 ± 0.2, the ratio of radius '$b_2$' of said second side core 4 and of radius 'a' of said centre core 2 [$b_2/a$] is about 2.5 ± 0.2, the ratio of radius '$b_3$' of said cladding region 5 and of radius 'a' of said centre core 2 [$b_3/a$] is about 3.7 ± 0.2.

5. Dispersion optimized fiber according to claims 1 to 4, wherein $\Delta_1$, $\Delta_2$ and $\Delta_3$ are positive, but $\Delta_4$ is negative with reference to said outer glass 6.

6. Dispersion optimized fiber according to claims 1 to 5, wherein the attenuation of said fiber 1 at 1550 nm is less than or equal to about 0.22 dB/km, and mode field diameter of said fiber 1 at 1550 nm is about 8.4 to 9.4 micrometer, and effective area of said fiber 1 at 1550 nm is between about 55 to 65 micron$^2$, and the cut-off wavelength of said fiber 1 is less than about 1250 nm, and the polarization mode dispersion of said fiber 1 is less than about 0.25 ps/km$^{0.5}$.

7. Dispersion optimized fiber according to claims 1 to 5, wherein the

chromatic dispersion of said fiber 1 in 1530 – 1565 nm range is about 2 to 8 ps/nm-km, and the microbending loss of said fiber 1 is less than about 0.04 dB at 1550 nm.

8. Dispersion optimized fiber according to claims 1 to 5, wherein the dispersion slope of said fiber 1 is about 0.060 ± 0.015 $ps/nm^2km$ over the predefined wavelength region, and the zero chromatic dispersion of said fiber 1 lies in between about 1470 – 1510 nm wavelength region.

9. Dispersion optimized fiber according to claims 1 to 8, wherein said side cores 3 & 4 have a step index profile and said center core 2 has trapezoidal profile.

10. Dispersion optimized fiber according to claims 1 to 9, wherein said fiber 1 has calculated profile volume in the range of 8 $\%\mu m^2$ to 23 $\%\mu m^2$.

11. Dispersion optimized fiber according to claims 1 to 10, wherein said center core 2 of said fiber 1 is doped with germanium doped in $SiO_2$, and said first side core 3 of said fiber 1 is doped with germanium and fluorine doped in $SiO_2$, said second side core 4 of said fiber 1 is doped with germanium and fluorine doped in $SiO_2$, said depressed cladding region 5 of said fiber 1 is doped with germanium and fluorine doped in $SiO_2$.

12. Dispersion optimized fiber according to claim 11, wherein said center core 2 is doped preferably at 55 to 166 SCCm flow rate and preferably at 1920 to 1960$^0$C temperature, and said first side core 3 is doped preferably at 116 to 130 SCCm flow rate of germanium and preferably at 0.19 to 0.44 SCCm flow rate of fluorine and preferably at 1900 to 1916$^0$C temperature, and said second side core 4 is doped preferably at 105 to 115 SCCm flow rate of germanium and preferably at 0.19 to 0.78 SCCm flow rate of fluorine and preferably at 1860 to 1892$^0$C temperature and said depressed cladding region 5 is preferably at 90.4 to 100.4 SCCm flow rate of germanium and preferably at 0.75 to 1.1 SCCm flow rate of fluorine and preferably at 1800 to 1844$^0$C temperature.

13. Dispersion optimized fiber as claimed and described herein above with the help of the accompanying figures.

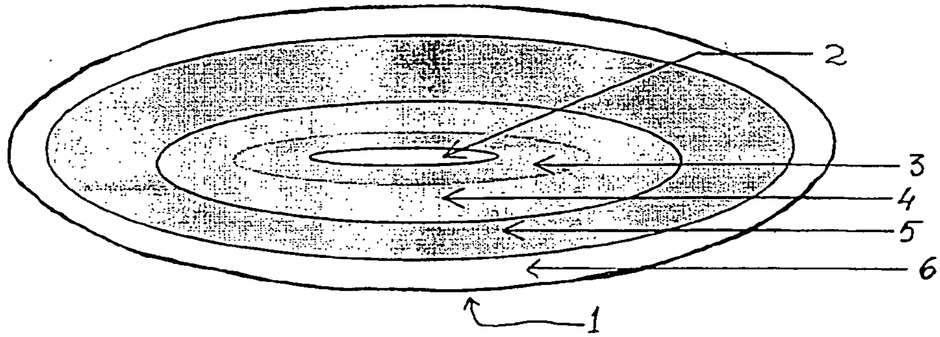


Figure - 1a

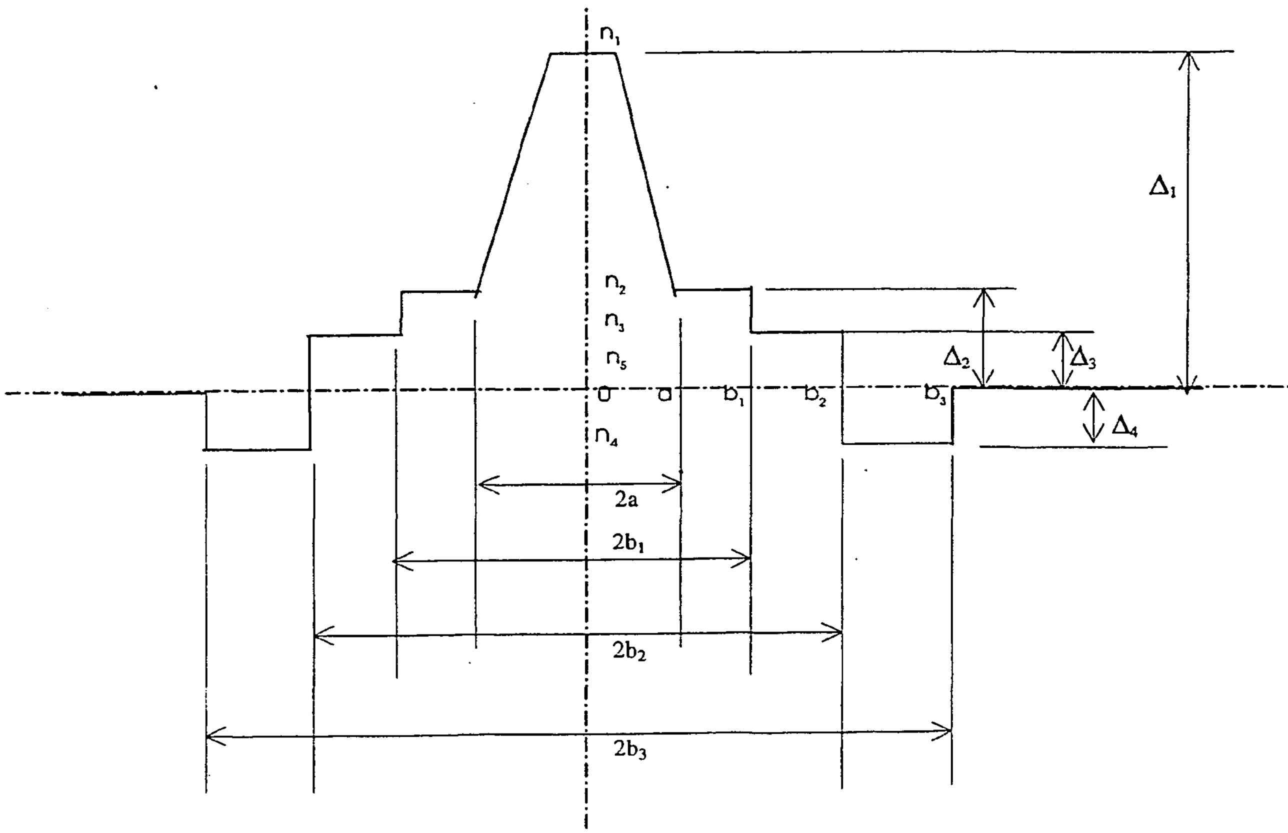


Figure - 1b

Figure - 1

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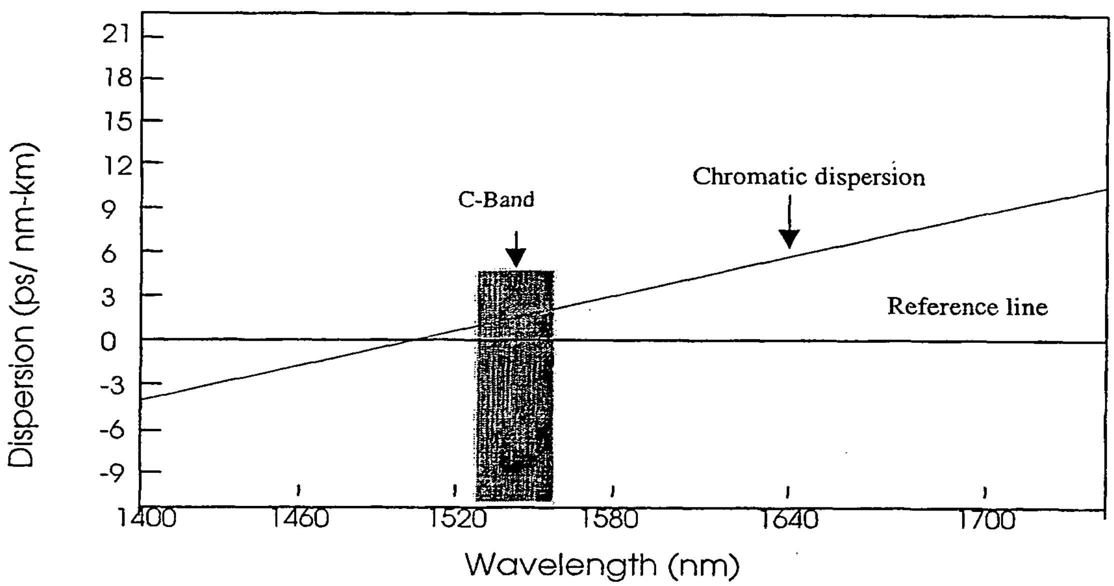
Dispersion (ps/ nm-km)
21
18
15
12
9
6
3
0
-3
-6
-9
C-Band
Chromatic dispersion
Reference line
1400
1460
1520
1580
1640
1700
Wavelength (nm)

Figure - 2

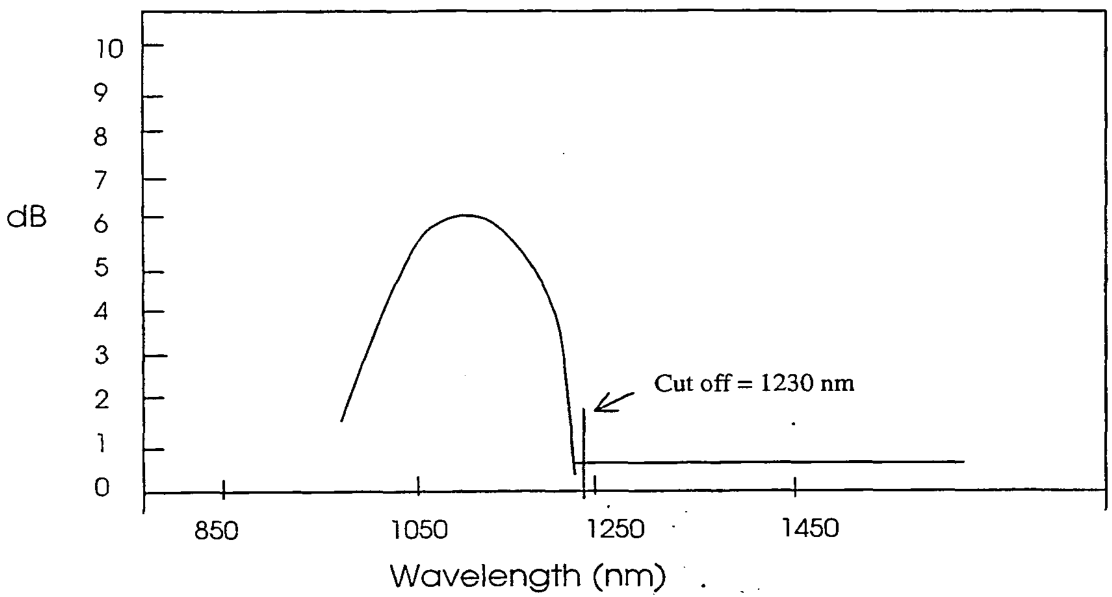
10
9
8
7
dB
6
5
4
3
2
1
0
Cut off = 1230 nm
850
1050
1250
1450
Wavelength (nm)

Figure - 3

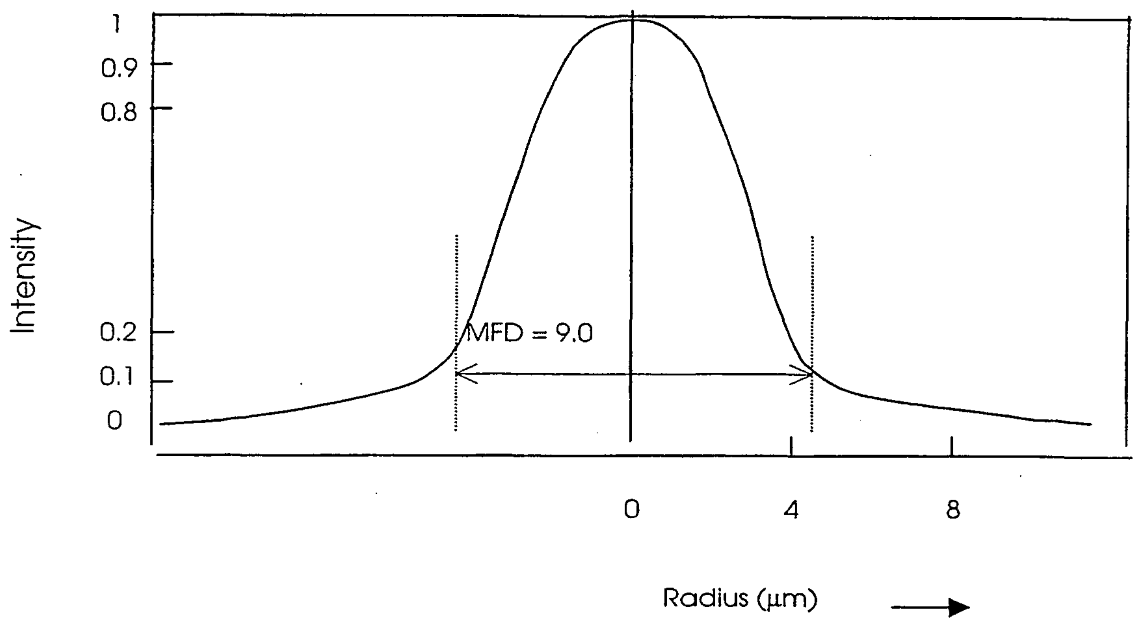


Figure - 4

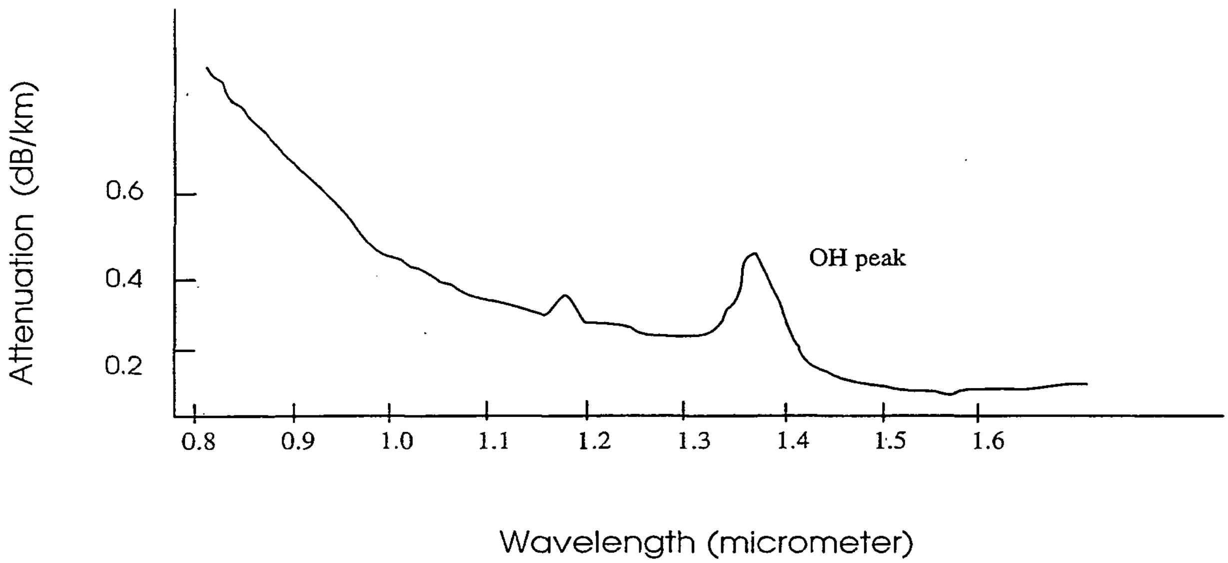
Attenuation (dB/km)
0.6
0.4
0.2
OH peak
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
Wavelength (micrometer)

Figure - 5

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/IN 00/00092

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G02B6/22 G02B6/16

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, INSPEC

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | PATENT ABSTRACTS OF JAPAN vol. 1998, no. 12, 31 October 1998 (1998-10-31) & JP 10 186156 A (FURUKAWA ELECTRIC CO LTD:THE), 14 July 1998 (1998-07-14) abstract --- | 1,2,9 |
| A | PATENT ABSTRACTS OF JAPAN vol. 1999, no. 13, 30 November 1999 (1999-11-30) & JP 11 218632 A (FURUKAWA ELECTRIC CO LTD:THE), 10 August 1999 (1999-08-10) abstract --- | 1,2 |

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 10 August 2001 | 21/08/2001 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL – 2280 HV Rijswijk<br>Tel. (+31–70) 340–2040, Tx. 31 651 epo nl,<br>Fax: (+31–70) 340–3016 | Mathyssek, K |

Form PCT/ISA/210 (second sheet) (July 1992)

## INTERNATIONAL SEARCH REPORT

International Application No
PCT/IN 00/00092

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | PATENT ABSTRACTS OF JAPAN<br>vol. 1998, no. 12,<br>31 October 1998 (1998-10-31)<br>& JP 10 186157 A (SUMITOMO ELECTRIC IND LTD), 14 July 1998 (1998-07-14)<br>abstract<br>--- | 1,2 |
| A | US 4 715 679 A (BHAGAVATULA VENKATA A)<br>29 December 1987 (1987-12-29)<br>claims; figures 1,2,7-10<br>column 3, line 42 - line 68<br>column 4, line 1 - line 3<br>column 5, line 24 - line 68<br>column 6, line 1 - line 68<br>column 7, line 1 - line 68<br>column 8, line 1 - line 8<br>--- | 1,3,6 |
| A | EP 0 789 257 A (SUMITOMO ELECTRIC INDUSTRIES) 13 August 1997 (1997-08-13)<br>claims; figures 12-15<br>column 12, line 21 - line 59<br>column 13, line 1 - line 55<br>column 14, line 1 - line 34<br>--- | 1,3,6,10 |
| A | EP 0 785 448 A (SUMITOMO ELECTRIC INDUSTRIES) 23 July 1997 (1997-07-23)<br>figures 3-10<br>column 9 -column 14<br>column 15, line 1 - line 40<br>--- | 1,6,11 |
| A | EP 0 909 964 A (FUJIKURA LTD)<br>21 April 1999 (1999-04-21)<br>claims; figure 1; tables 1,2<br>page 3, line 22 - line 58<br>page 4, line 1 - line 56<br>----- | 1,6,8 |

## INTERNATIONAL SEARCH REPORT

Interr l Application No
PCT/IN 00/00092

| Patent document cited in search report | | Publication date | Patent family member(s) | | | Publication date |
|---|---|---|---|---|---|---|
| JP 10186156 | A | 14-07-1998 | NONE | | | |
| JP 11218632 | A | 10-08-1999 | NONE | | | |
| JP 10186157 | A | 14-07-1998 | EP | 0844501 | A | 27-05-1998 |
| US 4715679 | A | 29-12-1987 | AT | 46770 | T | 15-10-1989 |
| | | | AU | 555648 | B | 02-10-1986 |
| | | | AU | 9104282 | A | 16-06-1983 |
| | | | BR | 8206652 | A | 01-11-1983 |
| | | | CA | 1205307 | A | 03-06-1986 |
| | | | DE | 3279964 | D | 02-11-1989 |
| | | | DK | 502282 | A,B, | 08-06-1983 |
| | | | EP | 0083843 | A | 20-07-1983 |
| | | | ES | 517508 | D | 01-10-1983 |
| | | | ES | 8308641 | A | 01-12-1983 |
| | | | FI | 824178 | A,B, | 08-06-1983 |
| | | | IL | 67211 | A | 28-02-1986 |
| | | | IN | 156700 | A | 19-10-1985 |
| | | | JP | 1643785 | C | 28-02-1992 |
| | | | JP | 3005721 | B | 28-01-1991 |
| | | | JP | 58104040 | A | 21-06-1983 |
| | | | KR | 8801339 | B | 25-07-1988 |
| | | | MX | 152385 | A | 09-07-1985 |
| | | | NO | 824089 | A,B, | 08-06-1983 |
| | | | AT | 48479 | T | 15-12-1989 |
| | | | AU | 561632 | B | 14-05-1987 |
| | | | AU | 2808684 | A | 22-11-1984 |
| | | | BR | 8402305 | A | 26-12-1984 |
| | | | CA | 1246363 | A | 13-12-1988 |
| | | | DE | 3480665 | D | 11-01-1990 |
| | | | DK | 246784 | A,B | 21-11-1984 |
| | | | EP | 0127408 | A | 05-12-1984 |
| | | | ES | 532253 | D | 01-04-1986 |
| | | | ES | 8606674 | A | 01-10-1986 |
| | | | FI | 841998 | A,B, | 21-11-1984 |
| | | | HK | 88790 | A | 09-11-1990 |
| | | | IL | 71644 | A | 30-11-1987 |
| | | | IN | 160397 | A | 11-07-1987 |
| | | | JP | 59226301 | A | 19-12-1984 |
| | | | KR | 9107895 | B | 04-10-1991 |
| | | | MX | 158483 | A | 03-02-1989 |
| | | | NO | 841986 | A,B, | 21-11-1984 |
| | | | SG | 73990 | G | 23-11-1990 |
| EP 0789257 | A | 13-08-1997 | JP | 9218318 | A | 19-08-1997 |
| | | | AU | 710444 | B | 23-09-1999 |
| | | | AU | 1230197 | A | 14-08-1997 |
| | | | US | 5852701 | A | 22-12-1998 |
| EP 0785448 | A | 23-07-1997 | AU | 712202 | B | 28-10-1999 |
| | | | AU | 7647596 | A | 24-07-1997 |
| | | | CA | 2193542 | A | 17-07-1997 |
| | | | JP | 9258054 | A | 03-10-1997 |
| | | | KR | 244384 | B | 02-03-2000 |
| | | | US | 5721800 | A | 24-02-1998 |
| EP 0909964 | A | 21-04-1999 | JP | 11119045 | A | 30-04-1999 |

# INTERNATIONAL SEARCH REPORT

Interr      il Application No
PCT/IN 00/00092

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| EP 0909964 A | | US 6091873 A | 18-07-2000 |